AFOSR-TR-97

0557

REPORT DOCUMENTATION PAGE

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED
FINAL 01 Jul 93 to 30 Jun 97

4. TITLE AND SUBTITLE
INTERDISCIPLINARY TRAINING IN VISUAL SCIENCES

5. FUNDING NUMBERS
F49620-93-1-0408
3484/YS
61103D

6. AUTHOR(S)
Dr Eileen Kowler

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Dept of Psychology
Rutgers University
Psychology Building, Busch Campus
New Brunswick NJ 08903

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NL
110 Duncan Ave Room B115
Bolling AFB DC 20332-8050

Maj William P. Roach

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

19971103 083

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT

Approved for public release;
distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Our results thus far indicate that with the displays we have used the oculomotor and cognitive systems function with remarkable efficiency. For example, by linking saccadic target selection to the same attentional filter that serves perception it becomes unnecessary for observers to make a separate decision about where to aim the eye. The line of sight will automatically go to the attended region after a "go" signal is issued to trigger the movement. MOreover, the limitations on the attentional demands of saccades, which we have observed, mean that considerable resources are available for selection of potential targets before the saccade is initiated. Finally, the finding of a highly-precise spatial pooling process means that observers need only select a target object; the precise endpoint of the saccade is determined automatically by lower-level visuomotor processes that do not requrie deliberate or cognitive intervention. All of these principles may prove of value in the design of artificial visual systems that must aim sensors to selected targets in large visual scenes.

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
(U)	(U)	(U)	(UL)

THE STATE UNIVERSITY OF NEW JERSEY
RUTGERS
Department of Psychology
Psychology Building, Busch Campus, New Brunswick, NJ 08903
Office and Laboratory: (732) 445-2086; Department: (732) 445-2253; Fax: (732) 445-2263
email: kowler@rci.rutgers.edu

"Interdisciplinary training in vision"
AASERT F49620-93-1-0408

Final Progress Report 1994-1996

Principal Investigator:

Eileen Kowler
Department of Psychology
Rutgers University
New Brunswick, NJ 08903

AASERT F49620-93-1-0408 **PI: Kowler, E.**

2. Objectives (unchanged)

Students will participate in an interdisciplinary research project on oculomotor localization. The main objective of the project is to understand how human beings direct saccades accurately to spatially-extended targets. The projects to be undertaken are based on work from the PI's oculomotor laboratory, demonstrating a spatial-pooling process, which automatically and effortlessly uses information in a selected eccentric target form to compute a single, centrally-located saccadic landing position. Now, we want to understand how this spatial-pooling process works and to develop an information-processing model that accurately predicts saccadic landing positions. This project will be valuable both for understanding how the brain represents the location of spatially-extended targets and for developing efficient algorithms that direct the sensors or arms of robots to specific locations within spatially-extended targets.

Our approach is novel in its interdisciplinary nature: it is an attempt to extend mathematical models, developed to account for human visual detection and discrimination, to the "higher-level" problem of motor localization. The project involves a collaboration between the PI, whose area of expertise is human oculomotor control, and scientists at the nearby Sarnoff Laboratories, who have been developing mathematical models of visual discrimination. The AASERT students participate in both the empirical and theoretical phases of the collaboration, while pursuing a course of study that emphasizes training in cognitive science, visual science, psychophysics, mathematical modeling, and motor control.

3. Status of effort

Two graduate students have been supported: Dan Bahcall and James McGowan. Bahcall's work has concentrated on higher-level aspects of oculomotor control, namely, spatial attention. McGowan has been studying the lower-level sensory processes that guide saccades to a central-reference position within attended targets. Both students have completed coursework in sensory processes, perception, computer vision, computational models of cognition, and attention, as well as graduate level courses in advanced statistical theory, neural networks, and mathematical logic. Training has been broadened through interaction with specialists in vision research and mathematical psychology: (1) J. Bergen (Sarnoff Labs), who is collaborating with McGowan on saccadic localization experiments using spatially-filtered targets, (2) C. Chubb (Rutgers), who has collaborated with McGowan on saccadic localization experiments and also worked independently with McGowan on models of visual motion detection, (3) B. Dosher (U.C. Irvine) who is collaborating with Bahcall on experiments in spatial attention. Two undergraduate students have been supported: E. Anderson, who collaborated with Dosher and myself on experiments on saccades and attention and C. Araujo, a computer science major, and now a graduate student in philosophy, who has begun working on experiments looking at the cognitive control of eye

movements during visual search. In addition, D. Melcher, a graduate student, has been working on saccadic localization of spatially-structured targets.

4. Accomplishments and new findings

(a) Saccades and attention: AASERT student: E. Anderson (undergraduate honors thesis). These experiments explored the nature of the selective filter that guides saccades to chosen objects. We asked whether the a single selective filter serves both perception and eye movements or whether the saccadic system employed its own, independent filter. If a shared selective filter is involved, then it would not be possible to prepare to look at one object while at the same time paying full perceptual attention to something else. We devised several "dual-task" experiments (concurrent measures of saccades and perception) requiring subjects to look at one target while identifying another. Considerable effort was devoted to development of dual-task methods that placed subjects' strategies under tight experimental control. We found that identification of a perceptual target (a randomly-chosen letter) was better at the saccadic goal than elsewhere. Surprisingly, it was possible to accurately identify a letter at a location other than the saccadic goal by increasing saccadic latency only 10-30%. These results show that saccadic programming does make demands on perceptual attention, but the atttentional demands are modest. To explain the results, we proposed that attention is not involved in saccadic programming until shortly before saccadic execution, and that it is at this time that the spatial parameters of the saccade are determined. One way to implement this process would by involving two systems, one that determines the saccadic goal (controlled by means of selective attention) and another that triggers the saccade. By setting the saccadic trigger to launch the saccade in response to the attentional shift, scanning would be both rapid and accurate while at the same time minimizing the need for time-consuming "on-line" decisions about when and where to aim the eye. (Kowler, Anderson, Dosher, and Blaser, 1995).

(b) Attentional interference: AASERT student: D. Bahcall. We performed a perceptual version of the experiment described above. Instead of looking at one target and trying to identify another, we asked subjects to identify two targets in a circular display (rad 4 deg) of 24 letters. Contrary to expectations, we found that target identification improved with increasing target separation. The interference was attentional and not sensory because the display configuration did not vary with target separation. These novel results demonstrate spatially-local limits on attentional resources. Attentional interference is useful in that it enhances the perceptibility of a single target against nearby neighbors. It also suggests that optimal visual performance would be achieved in displays in which important features are widely-spaced. Bahcall has modeled the data using difference-of-Gaussian filters. (Bahcall and Kowler, 1995 and submitted ms).

(c) Saccades to dot clusters: (McGowan, Kowler, Sharma and Chubb, in press): AASERT student: J. McGowan. The pooling process that guides saccades to spatially-extended targets was investigated by studying saccades made to 4 deg diam clusters of 20 random dots.

Landing positions came close to the center-of-gravity of the patterns. Precision was quite good, with SDs around the center-of-gravity equal < 10% of stimulus eccentricity. Correlations of saccadic landing position with the presence of a dot at any display location showed that dots from the entire display were taken into account in determining the landing position of the saccade. The prediction of saccadic landing position was improved by reducing the weight assigned to a dot due to the presence of neighboring dots, i.e., dots in sparse clusters were more influential than dots in dense clusters. The results can be accounted for by a 2-stage localization model. The first stage consists of an array of detectors centered around different portions of the pattern and the second stage averages the 'local signs' of the detectors.

(d) Saccades to spatially-filtered targets: (in progress). AASERT student: J. McGowan. The spatial pooling process is being investigated by studying the precision of saccades directed to Gabor patches (sinusoidal gratings whose contrast is modulated by a Gaussian envelope). The main objective is to find out whether saccades use the same set of spatial filters as the perceptual system, or whether some spatial frequencies, although visible, constitute ineffective (i.e., noisy) targets for saccades. Saccadic localization remains precise over a wide range of spatial frequencies (.5 to 10 cpd) and envelope sizes (SD=.5 to 1 deg), with precision suffering only when contrast reaches values close to threshold. These results show that saccadic localization is not dependent on particular banks of first-stage visual filters. (Kowler, McGowan, Bergen and Lubin.)

(e) Saccades to spatially-extended targets: shapes and surfaces vs. elements. (AASERT student D. Melcher). The targets for saccades were composed of dots arranged so that they looked like coherent shapes with obvious boundaries, rather than clusters of random dots. Saccades landed at the center-of-area of the shape, not at the centroid of the dot locations. Landing positions were unaffected by changing the density of dots along the contour or by adding dots to the interior of the form. Dense clusters of unattended dots superimposed at an arbitrarily chosen locations either on the boundary or inside the shape had no effect. Saccades to dot clusters created by randomly perturbing the locations of interior or contour dots landed closer to the center of area of the nominal shape than to the centroid of dot locations. Figures 1-3 show sample stimuli and the obtained mean landing positions. (Melcher and Kowler, ms in draft form).

The results show that the saccadic system represents the location of the object irrespective of its component elements or internal structure. This agrees with intuitions that location is a fundamental property of an object and should be independent of how an object is constructed. The contribution of these experiments was to show that a precise representation of object location is available, that such a representation is actually used to guide saccades (in contrast to an element-based representation), and that the representation is accessible with no special effort required to either find the landing position or to avoid an influence of element spacing or internal structure.

It is possible that the object representations that guide saccades can be generated by the local sign model described above (see c, above) if we allow the responses of local units to be

sensitive to spatial position of the elements falling in their receptive fields. So, for example, 3 collinear elements would produce a stronger response than 3 haphazardly positioned elements. Follow-up experiments will use sparser clusters of dots (n<10) to test this idea. We will be looking for the pooling algorithm that gives the best prediction of landing position. Essentially, we are looking for the rules used to generate a higher-order representation of shape from component elements. The saccadic localization response is a novel way of testing such models.

(f) Saccades in visual search.: This is a new project in early pilot stages and thus must be described in somewhat greater detail than those above. The objective is to apply our understanding of saccadic control (studied in projects a-e) to understand performance in naturalistic and purposeful tasks requiring saccades (Araujo, Kowler and Pavel).

We have been studying visual search. There are two major constraints on determining a search path. One is the use of probabilistic information about where targets are likely to be located; we assume that a good strategy would be to search first in those locations most likely to contain the target. The second is constraints imposed by the mechanisms that have to carry out the search. If, for example, two high probability locations are far apart, and there is a great cost involved in traveling, it might be better to search nearby locations first, even if this means visiting a low probability location before a high probability location. The main question is how human beings combine these constraints to determine the search path. Any procedure used to combine constraints, which we will study in the context of an eye movement task, could presumably be applicable more generally to various kinds of searches.

We are beginning with a simple search task in order to identify constraints that apply to saccades and find out how these constraints trade off with locational probability. In the task (Figure 4) an observer must find as fast as possible a single letter T embedded in either one of two dense arrays of L's separated by 6 deg. Before the trial the observer is told the probability that the T will appear in the left or right array. Letter sizes and spacing were chosen so that in the actual displays it was not possible to discriminate a T from an L without looking right at it. The distance between initial fixation position and either array of letters is varied on each trial (this is done by setting the position of the fixation crosshair between the 2 arrays). Data shown in Figure 5 are latencies of the initial saccade (left graphs) and intersaccadic interval between first and second saccade (right graphs) for one subject as a function of initial fixation position. The two lines in each graph show performance when the high probability location was on the left (solid line) or right (dashed line). For this experiment the subject kept to a consistent strategy of always looking at the high probability location first. The results show that she was able to do this quickly when the high probability location was near the initial fixation position, but required considerable extra time when the high probability location was far away. This extra time was reflected not only in the latency of the initial saccade (left graphs), but also in the time before the second saccade (right graphs), an interesting outcome because the size of the second saccade was independent of the initial fixation position. This means that the results are due in part to the cost of using an awkward strategy (i.e., look at the high probability location first regardless of

distance) rather than solely cost of making large saccades. Given the cost of jumping across the display, a better strategy might have been to take distance into account.

Once some of the geometric constraints on saccades are identified (e.g., looking over large distances is difficult) it will become possible to design displays that pit probabilistic against geometric constraints and find out how observers elect to trade one for the other. These experiments could include the use of displays which change over time in predictable ways so that the observer's task becomes one of counting how many targets appear across a sequence of frames. This dynamic situation is interesting because the observer is required to use precisely timed saccadic sequences, which will introduce yet another set of constraints on saccades having to do with the tendency to pre-plan sequences of movements (Zingale and Kowler, 1987).

Using dynamic displays is also advisable because many important search situations require detecting targets that will appear only briefly. In such difficult situations -- where the eye must be in the right place at the right time and there is not much margin for error -- it becomes of great importance to achieve both accurate saccadic control and an optimal search strategy. The task becomes one of generating a correct prediction in space and time about target appearance and of transmitting these predictions to the oculomotor system. Our research has already shown that the sensory, motor and attentional mechanisms are in place to support accurate and precise saccadic control. The major limitation on the effectiveness of eye movements in real tasks may well be the ability to form accurate predictions and translate these predictions into plans for movement.

<u>Relevance and applications:</u> The experimental results are relevant to understanding the basic visual, cognitive and motor mechanisms that support accurate saccadic scanning. An understanding of both the attentional requirements of saccades and the visual displays that support accurate and precise scanning will contribute to the design of visual displays that produce optimal behavior, i.e., establishing a fast, accurate and precise scan pattern while at the same time freeing the most attentional resources for concurrent perceptual and cognitive tasks.

Our results thus far indicate that with the displays we have used the oculomotor and cognitive systems function with remarkable efficiency. For example, by linking saccadic target selection to the same attentional filter that serves perception it becomes unnecessary for observers to make a separate decision about where to aim the eye. The line of sight will automatically go to the attended region after a "go" signal is issued to trigger the movement. Moreover, the limitations on the attentional demands of saccades, which we have observed, mean that considerable resources are available for selection of potential targets before the saccade is initiated. Finally, the finding of a highly-precise spatial pooling process means that observers need only select a target object; the precise endpoint of the saccade is determined automatically by lower-level visuomotor processes that do not require deliberate or cognitive intervention. All of these principles may prove of value in the design of artificial visual systems that must aim sensors to selected targets in large visual scenes.

It is worthwhile noting that our information about saccadic scanning of natural visual scenes represents normal performance under optimal conditions, i.e., high-contrast, highly-visible displays inspected by highly-motivated and attentive observers. The performance under such conditions is remarkably good. These results serve as an important baseline with which to evaluate the expected deterioration of performance when optimal viewing conditions are unavailable, either because the visibility of the display or the cognitive state of the observer is impaired.

5. Personnel supported

Graduate students:

- Dan Bahcall (1994-1996)
- James McGowan (1994-1996)
- David Melcher (summer 1995 and 1996)

Undergraduate students:

- Christian Araujo (1994)
- Eric Anderson (1994)

6. Publications with AASERT students

Kowler, E., Anderson, E., Dosher, B. and Blaser, E. (1995) The role of attention in the programming of saccades. Vision Research, 1897-1916.

McGowan, J., Kowler, E., Sharma, A. and Chubb, C. Saccadic localization of random dot targets. Vision Research, in press.

Bahcall, D. and Kowler, E. Attentional interference at close spatial separations. Submitted.

7a. Talks

Kowler, E., Dosher, B., Anderson, E. and Blaser,E. Saccadic eye movements and shifts of visual attention. Psychonomic Society, November, 1993.

Bahcall, D.O. and Kowler, E. (1995) Attentional interference at close spatial separations. Investigative Ophthalmology and Visual Sciences Supplement, 36, S901.

McGowan, J., Kowler, E., Sharma, A. and Chubb, C. (1996) Precise saccadic localization of random dot targets. Investigative Ophthalmology and Visual Sciences Supplement, 37, S 524

Bahcall, D.O. and Kowler, E. (1996) Attentional interference at close spatial separations. European Conference on Visual Perception.

McGowan, J., Kowler, E., Sharma, A. and Chubb, C. (1996) Precise saccadic localization of random dot targets. European Conference on Visual Perception.

7b.c. None

8. New discoveries, patents, inventions. None

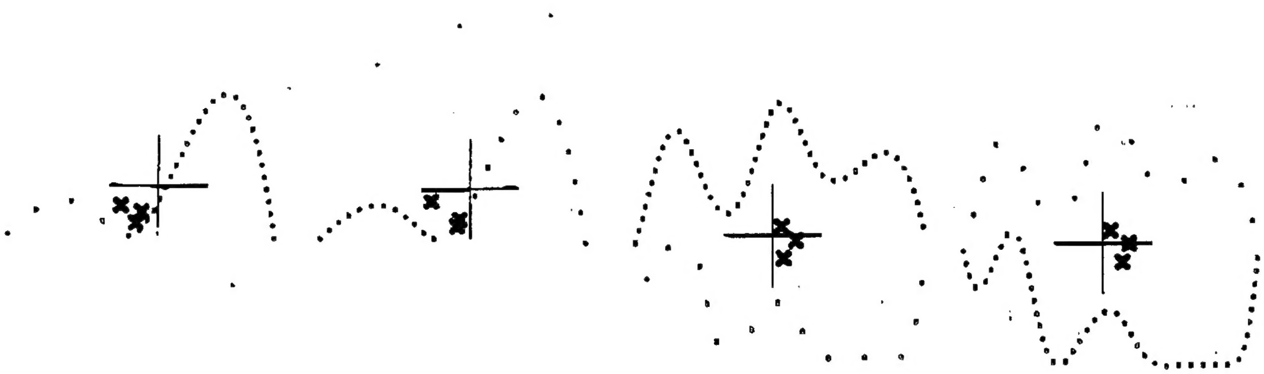

Figure 1. Mean landing positions of subject BS to four different targets. In the actual experiment, target orientation was varied and each x shows mean landing position for a different orientation. The large crosshair shows the centroid of the line connecting the dots (for the 2 targets on the left) and the centroid of the surface (for the 2 targets on the right). Landing positions correspond to these centroids, ignoring differences in dot spacing.

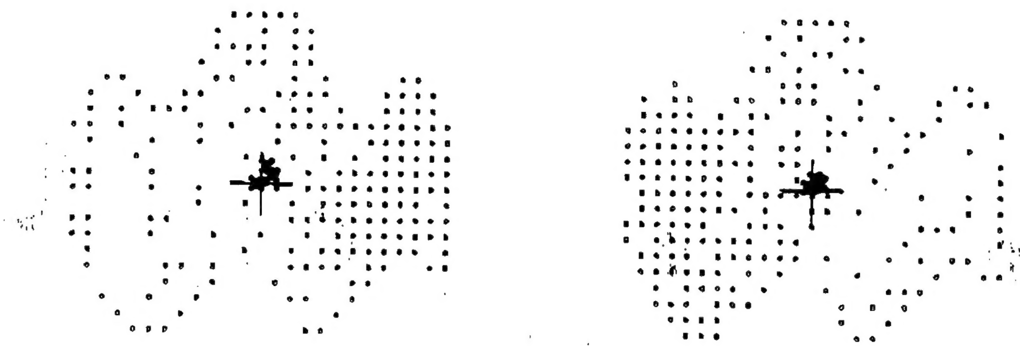

Figure 2. Mean landing positions of subject BS to two different targets. In the actual experiment, target orientation was varied and each x shows mean landing position for a different orientation. The large crosshair shows the centroid of the surface. Landing positions correspond to the centroid of the surface, not the center of gravity of the dot locations.

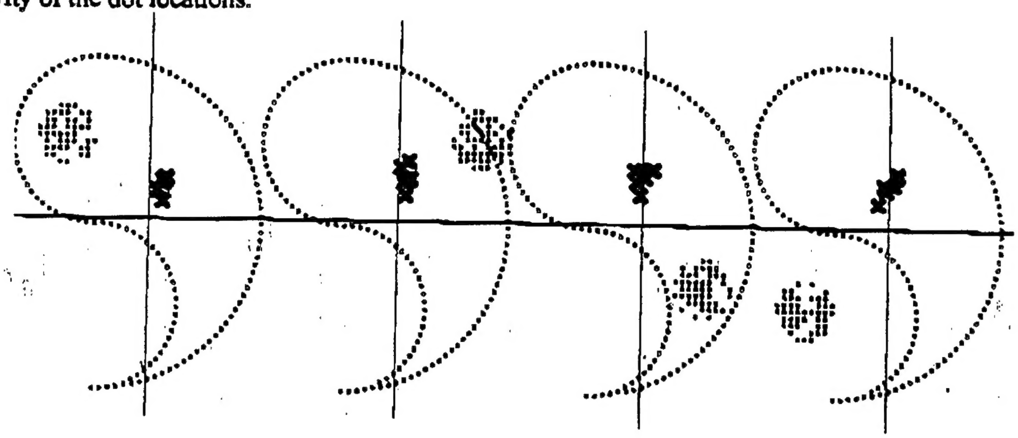

Figure 3. Mean landing positions of subject BS to four different targets. In the actual experiment, target orientation was varied and each x shows mean landing position for a different orientation. Landing positions were unaffected by the splotch of dots superimposed in, or, or just outside the target form.

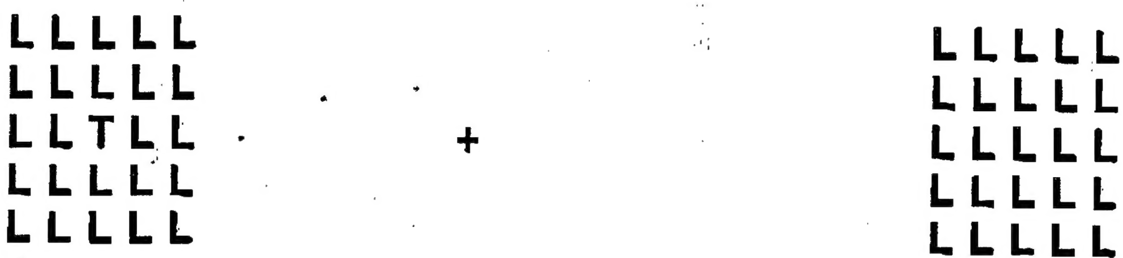

Figure 4. Sketch of stimulus in the search experiment. Subjects fixated the crosshair which could be at one of 6 positions between the two clusters of letters. One cluster contained the target letter T. The probablility of the T appearing on the left was either .8 or .6, cued before each trial. The task was to report the orientation of the T.

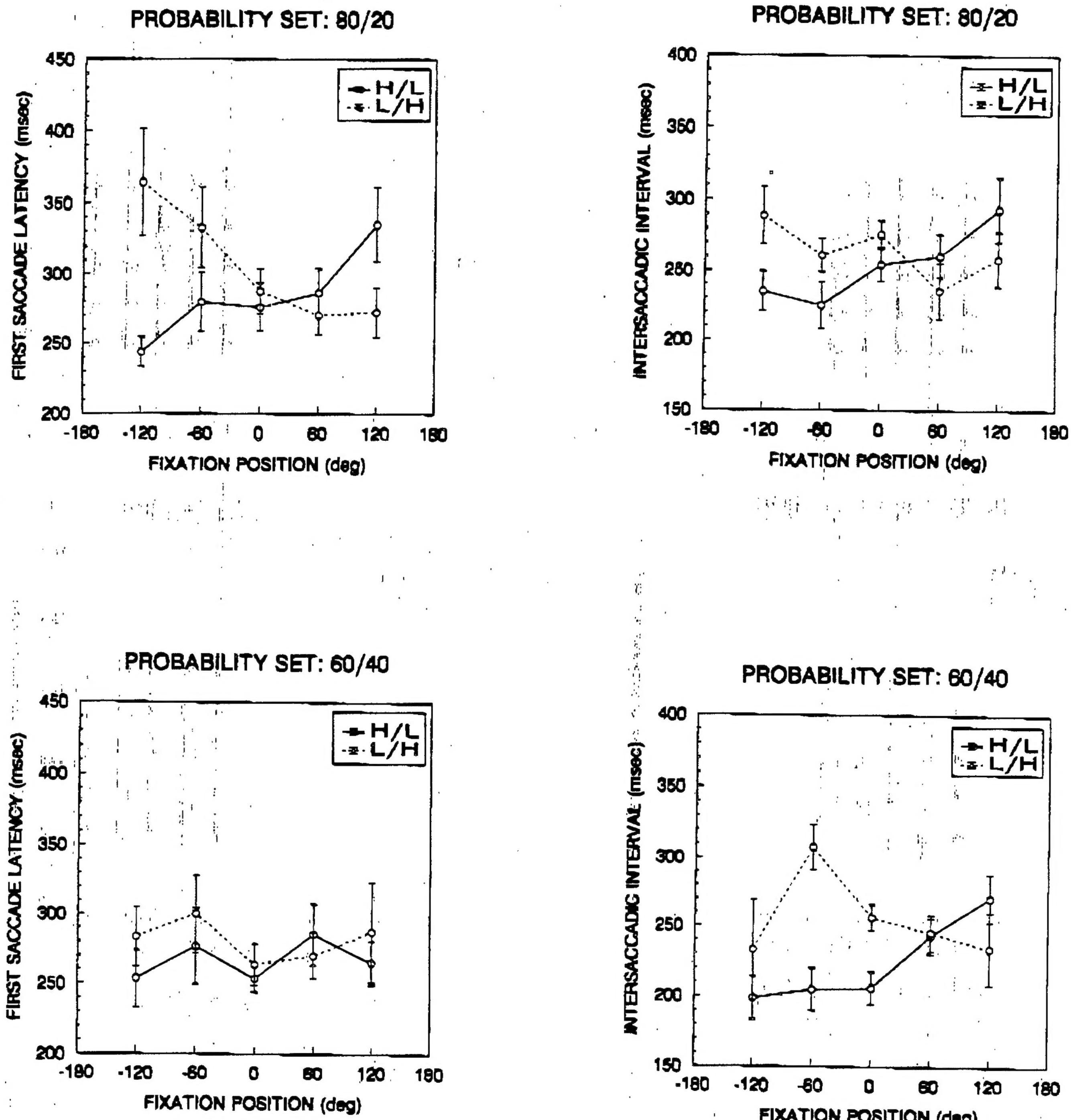

Figure 5. Latency of first saccade (left) and interval between saccades (right) for two different probabilities as a function of initial fixation position. Solid line: High probability location on the left; dashed line: high probability location on the right.